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PERSISTENCE AND TOXICITY OF PARATHION WHEN ADDED TO THE SOIL[1]

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The use of parathion for orchard spraying over a long period of time at heavy rates raised the possibility of toxic accumulations of this chemical in the soil. An investigation was carried out to obtain information on the following:

(*a*) The stability of parathion in the soil;

(*b*) The toxic effects of parathion on orchard cover crops and soil micro-organisms;

(*c*) The possibility of absorption of parathion from the soil by cover-crop vegetation.

In 1947, Questel and Connin (7) studied a large number of chemicals for systemic insecticidal properties. Parathion applied to the soil at a rate of approximately 1600 lb. per acre caused no observable injury to corn plants growing in this soil, and in some cases the treatment appeared beneficial. Either parathion or some toxic derivative, in quantities sufficient to kill feeding corn borer larvae, was absorbed by the roots and was translocated to the upper parts of the plants. These workers did not study the effects of parathion on seeds, on the growth and yield of plants grown on the treated soils or the amounts and persistence of parathion or its toxic derivatives in soils and plants.

Questel and Connin (8) in a more recent paper stated that corn growing in soil treated with a water suspension of parathion absorbed as much as 39 p.p.m. of parathion as determined by chemical methods. They noted that toxicity to the test insect first appeared in plants on the 15th day after planting. The peak was reached on the 21st day and by the 24th day most of the toxicity had been lost.

The American Cyanamid Company (2) reported that levels of parathion in the soil dropped 82 to 96 per cent within four months after treatment. The data presented were difficult to interpret, because in many cases the recoveries at harvest were in excess of the quantities applied to the soil. The discrepancies were attributed (5) to unsuitable mixing and sampling procedures.

The American Cyanamid Company (2) reported chemical and bioassay analyses of the parathion content of many plant species grown on treated soils. Lettuce plants, as well as other vegetables, grown on soil treated with 25 to 100 lb. of technical parathion per acre contained internal residues up to 0.1 p.p.m.

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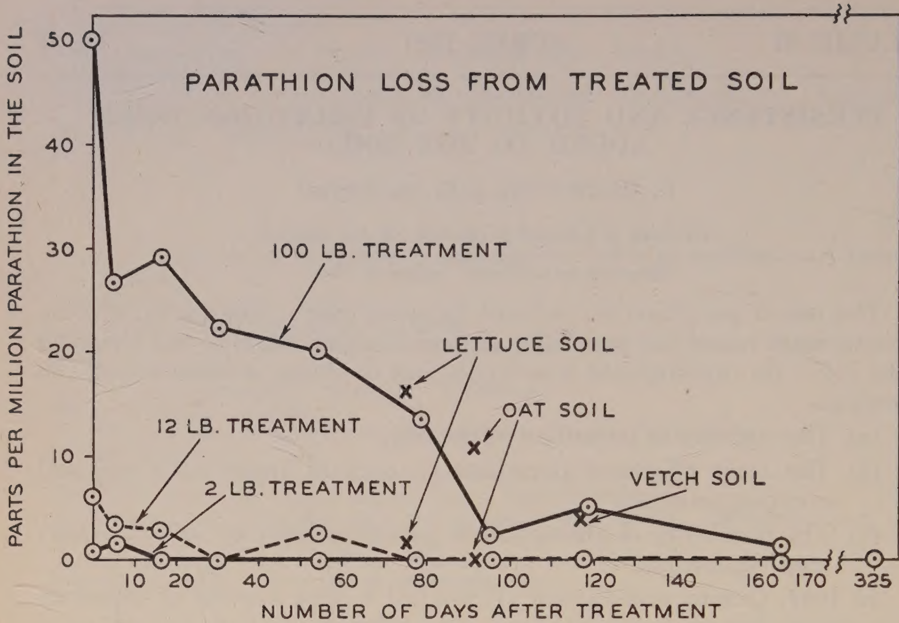

FIGURE 1. Loss of parathion from treated soils.

Gleissner (4) of the American Cyanamid Company stated that the quantities of internally absorbed parathion are of no practical significance from the public health standpoint since in his laboratories values in excess of 0.2 p.p.m. have not been obtained.

Martin as reported by J. K. Eaton (3) claimed that there was little if any evidence to show that parathion has systemic properties. The so-called systemic effects were attributed by him to fumigant action.

EXPERIMENTAL PROCEDURE

Three crops, lettuce, oats and vetch, were grown in untreated and parathion treated soil in one-half gallon pots under greenhouse conditions. A Latin square technique was used for each crop with four treatment levels, viz.: 0, 2, 12 and 100 lb. of technical parathion per acre, and with each treatment in quadruplicate.

The treatments applied to the cropped soils were also applied to a series of uncropped soils. This experiment was planned as a randomized block with three replicates per treatment. The soil was maintained at approximately 60 per cent of its moisture-holding capacity. Samples were taken at intervals for parathion and nitrate-nitrogen analyses and soil microbiological investigations. The cropped soils were analysed for parathion content at harvest.

A clay-loam soil of local origin with a pH of 6.8 was used in all experiments.

Field notes were made of the effects of the various treatments on germination and plant growth. Yield data were obtained by weighing he fresh vegetation at harvest.

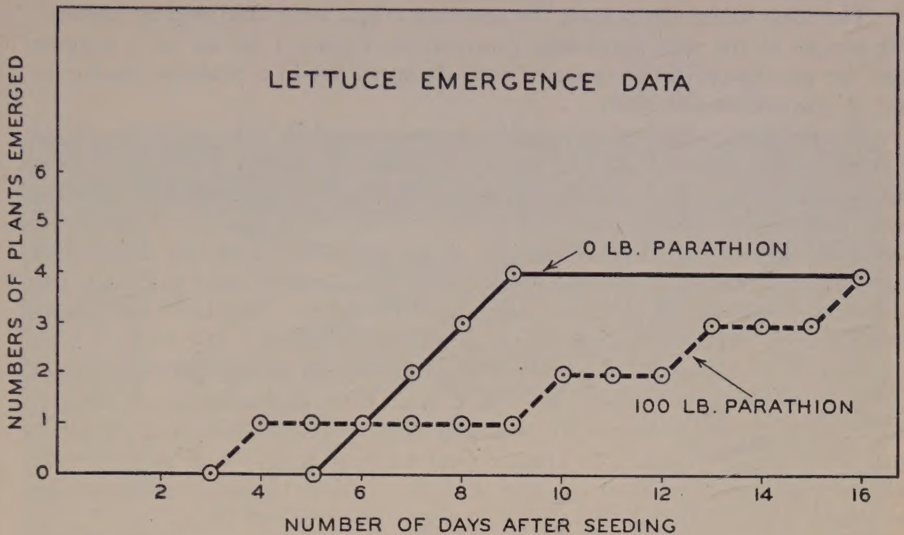

FIGURE 2. Effect of 100 lb. parathion soil treatment on the emergence of lettuce.

The green plants, above ground level, were analysed for parathion at approximately 40 days after seeding and at harvest. The plants were harvested at the marketing stage for lettuce, the boot stage for oats and the budding stage for vetch which represented 75, 87 and 109 days, respectively after seeding.

Ten- to twenty-gram samples of fresh plant material were extracted with 100 millilitres of benzene in a micro-Waring blendor. Thirty-gram samples of soil from each pot were dried with anhydrous sodium sulphate and extracted with 100 millilitres of benzene on a stroke-shaker. The colorimetric method of Averell and Norris (1) for parathion was applied to the benzene extracts.

Phosphorus determinations, using a modification of the method of King (6), were made on samples of oven-dried vegetation from each of the pots.

A roughly quantitative biological test, using the pomace fly (*Drosophila melanogaster*) as a test insect, was used as a check on the parathion analyses of the crops from the latest sampling date.

RESULTS

The average parathion content of the three replicates for the various treatments of the soil, determined at intervals and expressed as p.p.m. in oven-dry soil, are given in Figure 1.

Parathion persisted in all treated soils on the fifth day after treatment but was not detected after 16 days at the 2 lb. level or after 79 days at the 12 lb. level. The content in the soil from the 100 lb. treatment dropped to 1.2 p.p.m. (2.4 lb. per acre) at 165 days. A final check after 325 days showed at most only traces in any of the soils.

The soils which supported the growing crops were analysed at harvest. The means of the four replicates (marked on Figure 1 by an "x") suggest that the parathion of the cropped soils disappeared in a manner similar to that of the uncropped soils.

Standard microbiological techniques were used to determine the effect of parathion in the soil on the total numbers of bacteria, actinomycetes and fungi. There was a slight reduction at the 100 lb. level 5 days after treatment. This effect was not apparent at the other concentrations or at later sampling dates. Parathion had no apparent effect on the number of nitrifying, denitrifying, cellulose-decomposing, manganese-oxidizing or spore-forming bacteria at any of the sampling dates. Similarly the treatments had no effect on the quantity of nitrate-nitrogen in the soil.

The effect of the 100 lb. treatment of parathion on the germination of the lettuce seed is illustrated in Figure 2. There was a tendency for the 100 lb. and 12 lb. treatments to delay germination. After 16 days, however, all the seeds from both treated and untreated soils had germinated. The heavier treatments of 12 and 100 lb. tended to delay slightly the germination of vetch but there was no apparent effect on oats.

There were no visible differences in the size or vigour of the oat, lettuce or vetch plants attributable to soil treatment. The photographs shown in Figures 3, 4 and 5 were taken approximately 70 days after seeding and illustrate these conclusions.

The yields of the three crops at harvest were not affected by the parathion treatments.

The results of the earlier parathion analyses in parts per million of green vegetation of bulked replicates are shown in Figure 6. The concentration varied from 0.1 p.p.m. for the 2 lb. treatment in the oats to as much as 17.8 p.p.m. for the 100 lb. treatment in the vetch.

At harvest, as shown by the chemical analyses, there were at most only traces of parathion in the crops. The concentrations were not statistically significant but there was a slight upward trend for the oats and lettuce with increased parathion application to the soil.

Because of the possibility of the presence in the plant of toxic derivatives of parathion and because the chemical method under our conditions appeared unsuited to detect small quantities of parathion (0.5 p.p.m. or less) a biological test was used to analyse bulked benzene plant extracts.

Table 1 shows the percentage mortalities of pomace flies (*Drosophila melanogaster*) when exposed to benzene extracts of plant material from the latest sampling date.

Table 1.—Percentage mortalities of pomace flies when exposed to benzene extracts of plant material

Treatment, lb./acre	Percentage of mortality		
	Lettuce	Oats	Vetch
0	0	0	0
2	0	5	85
12	40	55	100
100	0	50	100

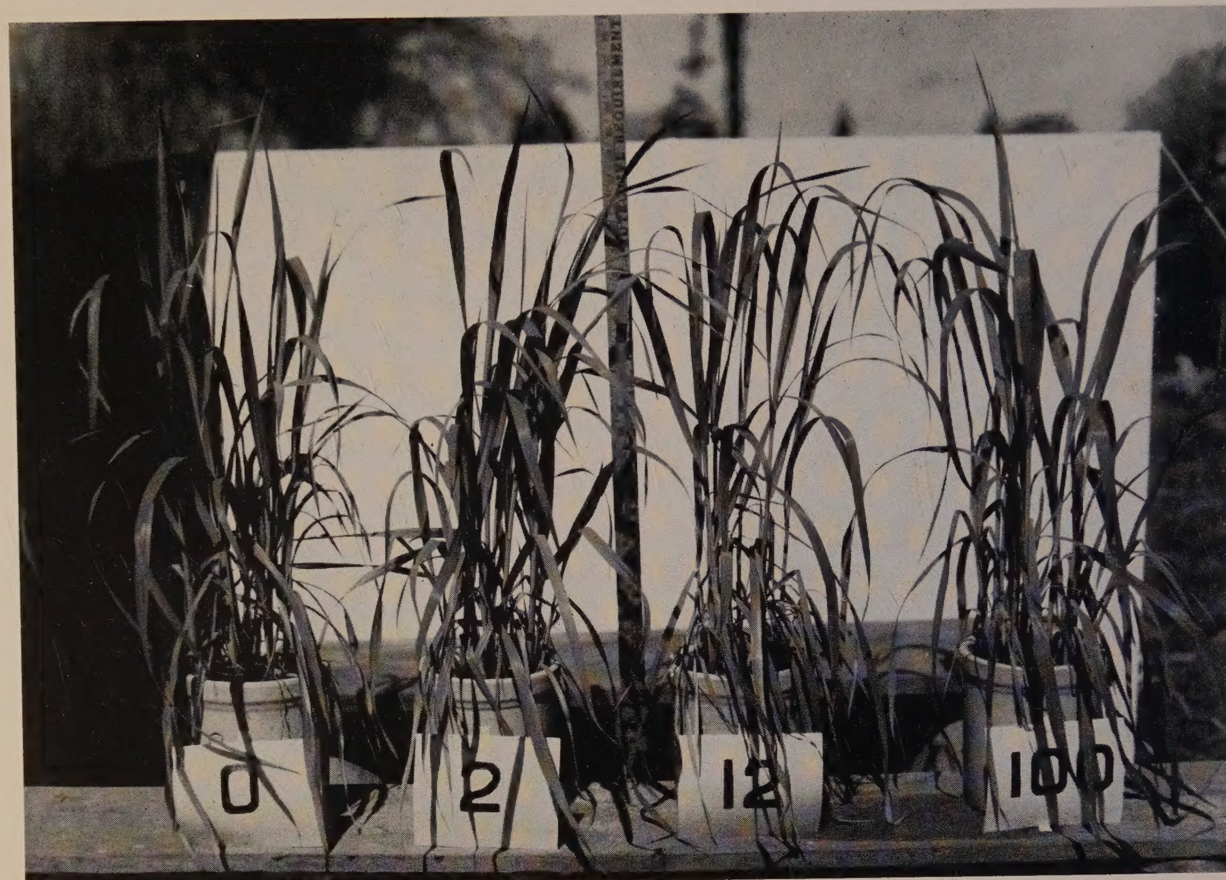

FIGURE 3. Effect of parathion soil treatment on growth of oats.

FIGURE 4. Effect of parathion soil treatment on growth of lettuce.

FIGURE 5. Effect of parathion soil treatment on growth of vetch.

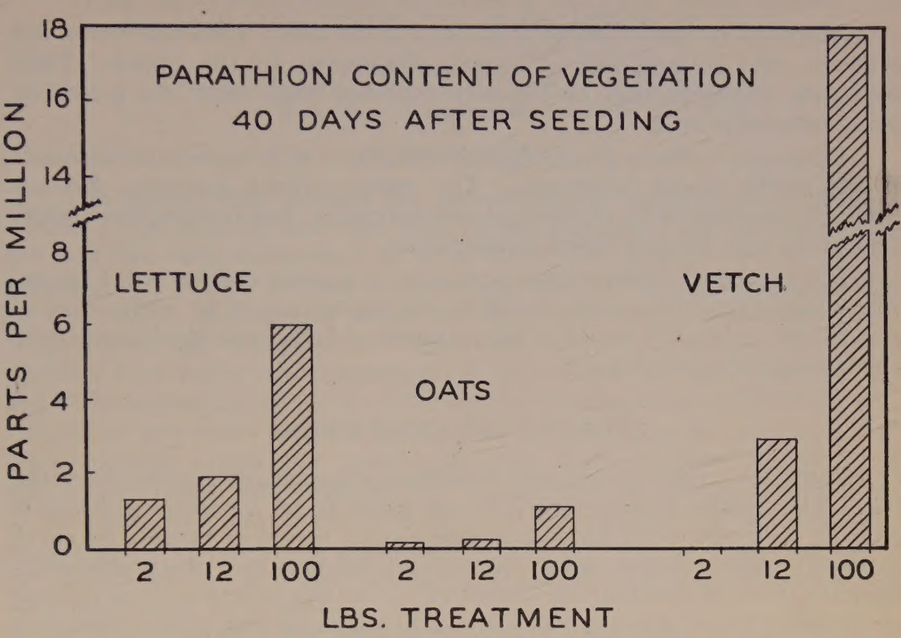

FIGURE 6. Parathion content of vegetation approximately forty days after seeding.

Toxic substances in the treated vetch, calculated as parathion, were estimated to be present in concentrations ranging between 0.05 and 0.5 p.p.m. Likewise, the concentrations in the oats of the 12 and 100 lb. treatments were estimated to be within the range of 0.02 to 0.1 p.p.m.

A small quantity (0.02 to 0.1 p.p.m.) of toxic material appeared to be present in the lettuce of the 12 lb. treatment. The minimum quantity of parathion detectable in lettuce under the conditions of the test was approximately 0.02 p.p.m. There was less than this quantity of toxic substance in the 2 and 100 lb. treatment.

It has been observed (9) that the treatment of plants with parathion has resulted in larger yields or more lush growth. This would suggest the possibility of a fertilizing or stimulating effect. In the present experiments there was no relation between yield and parathion treatment. There was a general trend toward increased phosphorus content with increased parathion application and statistically significant increases in oats and vetch at the 100 lb. treatment.

DISCUSSION

Parathion, under conditions of this study, did not persist in the soil for any great length of time. Even large quantities, in the absence of leaching, were reduced to relatively low levels in a single growing season.

Although parathion is a highly toxic chemical to insects and humans, there were no phytotoxic effects on the three crops studied. Further, this chemical did not seriously affect the balance of microbiological life in the soil. The observed effect on germination at the higher soil treatments would probably be of little significance under practical conditions.

Additions of parathion to this soil did not affect yield but there was evidence that it supplied additional phosphorus to the plants. Yield responses, therefore, may be logically expected when crops are grown on phosphorus poor soils.

There was evidence of parathion in the plants with appreciable amounts at the earlier stages of growth. The methods used, however, did not eliminate the possibility of external contamination due to fumigant action. This point is at present under investigation.

The suggested tolerance for parathion as a spray residue is 1.5 p.p.m. While larger quantities were found in the vegetation at an early stage of growth, the quantities found at harvest were of little or no significance from a toxicological point of view.

SUMMARY AND CONCLUSIONS

Parathion under greenhouse conditions disappeared rapidly from the soil. This would suggest that it is not likely to be a residue problem in orchard soils even with heavy spraying over a period of years. As much as 100 lb. parathion per acre in the soil did not have any observable detrimental effects on the plants or serious effects on the microbiological balance of the soil. Parathion may be beneficial to plants because of its phosphorus content. Although young plants from the heavier treatments contained relatively large quantities of parathion, the amounts present at harvest were not toxicologically significant.

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A PRELIMINARY STUDY OF THE APPLICATION OF THE PERCENTAGE YIELD CONCEPT TO THE RESPONSE OF FORAGE CROPS TO IRRIGATION WATER[1]

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INTRODUCTION

The relationship between the percentages of the maximum yields of several crops and the amounts of available potassium and phosphorus in the soil has been elaborated by Bray (1). The purpose of the present investigation was to determine to what extent this concept was applicable to the effects of irrigation water on the yields of certain forage crops. This approach to the problem of the efficiency of irrigation water tacitly assumes that water is a component of the plant nutrient complex in the soil. Since the percentage yield concept is so adequately established with respect to potassium and phosphorus, it is of the greatest importance to learn to what extent this useful approach to the problem of fertility is applicable to other factors in the nutritional complex of the soil. Certainly, if the use of irrigation water is subject to the same precise mathematical analysis, the economics of comparatively costly irrigation practices could be determined in advance, and a more sound planning of production programs would be possible.

The percentage yield concept is comparatively new and its value in the development of fertilizer programs is not very widely known. It is advisable, therefore, to explain this concept in some detail before its application to the use of irrigation water is described.

The most adequate explanation of the percentage yield concept that has yet appeared has been presented by Bray (1). The historical background for this concept of fertility and of response to fertilizers will be described briefly.

Liebig's Law of the Minimum

Liebig's statement of the law of the minimum is described in detail by Spillman (2). This author states that the yield of a crop is limited by the factor which is operating at the minimum intensity. This concept of

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TABLE 1.—THEORETICAL DATA SHOWING THE APPLICATION OF THE PERCENTAGE YIELD THEORY OF THE RESPONSE OF CROPS TO FERTILIZER

Treatment, other than fertilization with potassium	Yield without fertilization with potassium	Yield with adequate potassium (pounds)	Percentage increase due to potassium	Actual increase due to potassium
None	100	125	25	25
Phosphorus	120	150	25	30
Phosphorus and nitrogen	160	200	25	40

TABLE 2.—TREATMENTS OF THE EXPERIMENTAL PLOTS OF EXPERIMENT I

Plot No.	Fertilizer		Water
	Lb. per acre	Composition	
1	1000	2–12–6	Irrigated
2	None	—	Irrigated
3	1000	2–12–6	None
4	None	—	None

fertility is the approximate biological equivalent of the old adage that a chain is as strong as its weakest link. If this concept were valid, then no increase in yield would be expected by adding any fertilizer other than the one which is deficient to the greatest degree.

Sprengel actually preceded Liebig in voicing the essential features of the law of the minimum, for as early as 1837 he wrote (Brown, 1944) "The soil is often neither too stiff nor too porous, neither too wet nor too dry, neither too cold nor too warm, neither too high nor too low; it may be situated under very advantageous climatic conditions, it may contain a goodly proportion of electriable particles, it may have an abundant supply of hume and be located on a favourably inclined slope and yet may often be unproductive because it is deficient in *one single element* that is necessary as a food for plants".

The validity of the law of the minimum has been assumed because it sounds so reasonable, and it dominated the study of soil fertility for many years. Yet any accurately designed series of field plots will show that this concept is not true.

Mitscherlich's and Spillman's Law of Diminishing Returns

Spillman and Lang (2) stated that the increase in yield becomes smaller for each successive additional increase of fertilizer added. If this concept were true, there could be no thought of a maximum yield.

Baule's Percentage Yield Concept

Spillman and Lang (2) attempted to overcome the objections of the earlier theories of the quantitative response of crops to fertilizers by their percentage yield concept. This theory predicts that the yield is the product of all the factors which individually influence the yield, and that each nutrient exhibits a definite percentage sufficiency in terms of the maximum effect which it could exert if present in an optimum amount. In other words, if two nutrients are deficient, the yield is the product of the observed percentage of the maximum yield permitted by each of the nutrients. This theory obviously precludes the validity of either the law of the minimum or the law of diminishing returns, at least as originally proposed.

Bray's Mobility Concept

Bray's (1) recently published interpretation of crop response to fertilizer is a modification of Baule's percentage yield concept. It states that crop response to the nutritional ions exhibiting but little mobility in

TABLE 3.—DISTRIBUTION OF RAINFALL DURING THE GROWING SEASON, EXPRESSED IN INCHES

Date	Rainfall		Date	Rainfall	
	1948	1949		1948	1949
April	1.91	1.73	September	1.68	—
May	5.43	2.64	October	1.62	—
June	2.94	2.45			
July	1.17	—	*Total*	15.73	6.82
August	0.98	—			

the soil, such as phosphorus, potassium, calcium, and magnesium, follows Baule's percentage yield theory, but that the more mobile nutrients, such as the nitrate ion and water, tend to follow Liebig's law of the minimum.

Each of the concepts of fertility and of response to fertilizers described above must be borne in mind in evaluating the percentage yield concept, and especially when it is applied to the interpretation of individual nutritional factors. With the above brief historical background in mind, we may present a more detailed discussion of the percentage yield concept itself.

Let us suppose that both phosphorus and potassium are deficient in the soil, that is to say, that the yield would increase if either of these nutrients were added as a fertilizer. Let us also assume that the observed yield, when neither of these nutrients was added to the soil, was 100 arbitrary units. By experiment, we might find that the yield would be 120 if an adequate amount of phosphorus were present. Obviously then, the addition of the phosphorus increased the yield 20 per cent, or to a total of 120 units.

By experiment, we might find that an adequate amount of potassium would increase the yield from 100 units to 125. This would indicate that the added potassium increased the yield 25 per cent or to a total of 125 units.

Now, each of these percentages of increase occurs, irrespective of other factors. Hence phosphorus alone increased the yield 20 per cent or $100 + 20 = 120$. If potassium were *also* added, its effect would be to increase the value of 120 by 25 per cent or to $120 + 30 = 150$. The bonus for having added both nutrients, over the sum of what each would have produced if added alone is seen to be 5 per cent of the original, unfertilized yield.

TABLE 4.—DRY MATTER PRODUCED BY THE EXPERIMENTAL PLOTS OF EXPERIMENT I, EXPRESSED AS POUNDS PER ACRE

Plot No.	Irrigation treatment	Fertilizer treatment	Yields of dry matter			
			First harvest	Second harvest	Third harvest	Total
1	Irrigated	Fertilized	1750	1750	550	4050
2	Irrigated	Unfertilized	920	760	260	1940
3	Not irrigated	Fertilized	560	440	—	1000
4	Not irrigated	Unfertilized	650	280	—	930

TABLE 5.—INCREASES IN YIELD DUE TO IRRIGATION WATER, OBTAINED IN EXPERIMENT I, EXPRESSED IN POUNDS PER ACRE

Plot No.	Treatment	Increase per crop		Total increase	
		First crop	Second crop	On basis of 2 crops	On basis of 3 crops
1	Fertilized	1190	1310	2500	3050
2	Unfertilized	270	480	750	1010

TABLE 6.—INCREASE IN YIELD DUE TO IRRIGATION WATER, OBTAINED IN EXPERIMENT I, EXPRESSED AS PERCENTAGES OF THE CORRESPONDING UNIRRIGATED HARVESTS

Plot No.	Treatment	Increase per crop		Total increase	
		First crop	Second crop	On basis of 2 crops	On basis of 3 crops
1	Fertilized	213	298	250	305
2	Unfertilized	42	171	81	108

The critical test of the validity of this percentage yield concept would depend on first discovering the percentage increase in yield which the addition of a specific nutrient would bring forth. Then, this observed percentage increase should remain at a constant magnitude even if the original yield be varied by other means. If adequate potassium increases the yield 25 per cent, then this percentage should remain the same, even if the original yield obtained without potassium fertilization were 100, or 150 arbitrary units. Table 1 represents theoretical data showing the application of the percentage yield concept to the response of a crop to fertilization with potassium.

These imaginary data indicate that if the percentage yield concept is valid, the actual increase in yield in absolute terms may vary from 25 to 40 arbitrary units although the effect of an adequate supply of potassium increased the yield 25 per cent in each case, irrespective of the increases produced by other factors. It is easy to see that *the addition of any single nutrient might be unprofitable to the farmer, but the addition of a complete fertilizer might be very profitable indeed.*

The purpose of the present investigation was to determine to what extent the response of a crop to irrigation water followed the percentage yield concept. In order to accomplish this, equal amounts of water were applied to plots variously fertilized as indicated in Table 2.

EXPERIMENT I

Experimental Materials and Methods

The field experiments were carried out on a Thames clay loam soil, near Wallaceburg, Ontario, Canada, during the growing season of 1948. Irrigation water was applied by a portable sprinkler system which delivered approximately one inch of water per acre per hour. The experimental area was 20 acres in extent, and it was selected to represent uniform soil conditions.

TABLE 7.—INCREASES IN YIELD DUE TO FERTILIZER TREATMENTS OF EXPERIMENT I, EXPRESSED AS POUNDS PER ACRE

Plot No.	Treatment	Increase per crop			Total increase	
		First crop	Second crop	Third crop	On basis of 2 crops	On basis of 3 crops
1	Irrigated	830	990	290	1820	2110
3	Not irrigated	−90	160	—	70	—

TABLE 8.—INCREASES IN YIELD DUE TO FERTILIZER TREATMENTS OF EXPERIMENT I, EXPRESSED AS PERCENTAGES OF THE CORRESPONDING CONTROL VALUES

Plot No.	Treatment	Increase per crop			Total increase	
		First crop	Second crop	Third crop	On basis of 2 crops	On basis of 3 crops
1	Irrigated	90	130	112	108	109
3	Not irrigated	−14	57	—	8	—

A mixture of Orchard grass, Meadow fescue and Ladino clover was sown in the spring of 1947 with oats as a nurse crop. This mixture was sown at the rate of 20 pounds per acre.

Four plots of 5 acres each were treated as indicated in Table 2. The entire twenty acres were harvested twice before being divided for experimental treatment. The fertilizer was applied on July 14, and irrigation water was applied on July 15. The rainfall during the growing season is recorded in Table 3. These data were obtained by the Canada and Dominion Sugar Company at Wallaceburg, Ontario. The recording instruments were located 3.5 miles from the experimental field.

The experimental field had been tiled at a depth of approximately 4 feet. Irrigation water was applied until excess water appeared in the drainage tile. The total amount applied was approximately 4 inches and it was certain that the soil profile was saturated to the depth of the drainage tile. The natural precipitation during the period of this experiment was 15.73 inches.

The herbage was harvested from all plots on August 17 and on September 20. A third harvest was obtained from the irrigated plots on October 18, but a third cutting was not possible on the unirrigated plots. The crops were dried immediately in a Arnold Rotary dehydrater in accordance with commercial practice.

Experimental Results

Effects of Irrigation Water

The yields of dry material expressed as pounds per acre are presented in Table 4, and the increases in yield due to irrigation are indicated in Table 5. The increases in yield, due to irrigation water, are expressed in Table 6 as percentages of the corresponding unirrigated yields.

The data in Table 5 show that a very great increase in the yield of dry matter was produced by irrigation *if fertilizer also was added.* Since the third harvest was made possible by irrigation, while only two harvests were obtained without irrigation, the total seasonal yield was still further augmented, but if the growth rates of the crops are considered individually, only the first two crops may be compared.

The data in Table 6 show that the yield per cutting was increased from 213 to 298 per cent by irrigation, if fertilizer also was added; but the increase was only from 42 to 171 per cent if water alone was used. If the total yields of dry matter are considered, it is evident that the percentage increase due to irrigation was about 3 times as great if fertilizer also was used. This is true if either two crops or three are involved in the calculation. It is apparent that the percentage increase in yield due to water *varied* with the nutritional state of the soil, hence the percentage yield concept is not applicable to the results obtained.

Effects of Fertilizer

It is also interesting to examine the effects which the fertilizer exerted on the yield of dry matter, with and without the addition of water. The data showing these effects of fertilizer are expressed as pounds of dry matter produced per acre in Table 7.

TABLE 9.—FERTILIZER TREATMENTS OF THE EXPERIMENTAL PLOTS OF EXPERIMENT II, EXPRESSED IN POUNDS PER ACRE

Plot No.	Irrigation treatment	Fertilizer applied		
		Superphosphate (0-20-0)	Potassium chloride (0-0-50)	Ammonium chloride (35-0-0)
1	Not irrigated	0	0	0
2	Not irrigated	400	200	0
3	Not irrigated	400	200	200
4	Irrigated	400	200	200
5	Irrigated	400	200	0
6	Irrigated	0	0	0

TABLE 10.—YIELDS OF DRY MATTER OBTAINED IN EXPERIMENT II, EXPRESSED AS POUNDS PER ACRE

Plot No.	Treatment		Yield
	Irrigation	Fertilizer	
1	Not irrigated	Unfertilized	834
2	Not irrigated	P + K	816
3	Not irrigated	P + K + N	1393
4	Irrigated	P + K + N	2152
5	Irrigated	P + K	1723
6	Irrigated	Unfertilized	1248

TABLE 11.—INCREASE IN YIELD DUE TO IRRIGATION WATER, EXPERIMENT II, EXPRESSED IN POUNDS PER ACRE

Plot No.	Fertilizer treatment	Yield increase due to irrigation
6	Unfertilized	414
5	P + K	907
4	P + K + N	759

TABLE 12.—INCREASES IN YIELD DUE TO IRRIGATION WATER, EXPERIMENT II, EXPRESSED AS PERCENTAGES OF THE CORRESPONDING CONTROL VALUES

Plot No.	Fertilizer treatment	Yield increase due to irrigation
6	Unfertilized	49
5	P + K	111
4	P + K + N	54

The fertilizer, when used without irrigation did not increase the yield of the first harvest, in fact the yield was actually less by 90 pounds per acre than when no fertilizer was used. However, a favourable effect of fertilizer was detected in the second harvest. The increase due to fertilizer was much greater when the plots were irrigated.

The percentage increase in the yields due to the fertilizer are indicated by the data assembled in Table 8. The fertilizer increased the yield 90, 130, and 112 per cent respectively for the 3 cuttings, if the plots were irrigated.

When the total season's growth, comprised of 3 cuttings, was considered, the increase due to fertilizer was 109 per cent. Unfortunately, the data for the non-irrigated plots is not comparable since there was no increase at all, but a decrease in yield of the first crop when fertilizer alone was used. The data are interesting, however, in that they show that the effect of irrigation *was 2.5 to 3.0 times as great as was that of the fertilizer.*

EXPERIMENT II

Experimental Materials and Methods

The plots used in Experiment II were approximately 1.68 acres in area. They were located on the Kentwood Farm, near Wallaceburg, Ontario. The soil was Thames clay loam.

Clinton oats were sown May 8, 1949, and harvested as green forage June 27. Approximately 2 inches of irrigation water was applied on May 10 and on June 12. The fertilizer treatments are indicated in Table 9.

A single cutting was obtained, and the material was dehydrated in an Arnold Rotary dehydrater as in Experiment I. The yields of dry material, expressed as pounds per acre, are presented in Table 10.

The increases in yield due to irrigation water are expressed in pounds per acre in Table 11, and these increases expressed as percentages of the corresponding controls appear in Table 12.

Table 13.—Increase in yield due to fertilizer, Experiment II, expressed as pounds per acre

Treatment	Yield increase due to fertilizer	
	PK	NPK
Not irrigated	−18	559
Irrigated	475	904

The data in Table 11 show that the actual increase in yield of dry matter of immature oats, expressed in pounds per acre due to irrigation varies greatly depending on the fertility of the soil. Yet the data in Table 12 show that the *percentage increase* due to water is about the same for the unfertilized and for the plots fertilized with superphosphate, potash, and ammonium nitrate. The percentage increase obtained on the plot which received superphosphate and potash was almost twice as large. This high value is due to the fact that the superphosphate and potash treatment itself gave no increase in yield *if water was not added.* Consequently, the irrigation water not only exerted its individual effect, which probably was about a 50 per cent increase, but it also permitted the superphosphate and potash to exert their effects. In the tabular data, however, the total increase appears erroneously to be due to water alone. It will be recalled that the fertilizer, 2-12-6, used in Experiment I, of the previous year, also failed to give a favourable response when water was not added. It is obviously impossible to compare the effects of water and fertilizer, if the fertilizer is prevented from giving any response because of a sub-minimum amount of water.

Bearing in mind the exceptional data just described, it appears that the effect of the irrigation water in this experiment tends to follow the percentage yield concept.

Effects of Fertilizer

The data have been reassembled in Table 13 to show the effects of the fertilizer treatments, with and without irrigation water. These data are expressed as percentages of the corresponding control yields in Table 14.

The data in Table 13 show that the superphosphate and potash fertilizer actually lessened the yield slightly when irrigation was not used. This result is in agreement essentially with the data of Experiment I which showed that the 2-12-6 fertilizer used in that experiment also lessened the yield of dry matter when water was not added also. When water was added in Experiment II, however, the superphosphate and potash fertilizer considerably increased the yield. The data assembled in Table 13 show that the superphosphate, potash, and ammonium nitrate fertilizer produced almost twice as great an increase in the yield of dry matter when irrigation water was added; yet the values in Table 14 show that the percentages increase were about the same, with or without the application of irrigation water. This pair of percentage values, namely 66 and 72, are so nearly equal that they indicate that the percentage yield concept is applicable to their interpretation.

TABLE 14.—INCREASE IN YIELD DUE TO FERTILIZER, EXPERIMENT II, EXPRESSED AS PERCENTAGES OF THE CORRESPONDING CONTROL VALUES

Treatment	Yield increase due to fertilizer	
	PK	NPK
Not irrigated	−2	66
Irrigated	38	72

It is interesting to note that the percentage increase due to fertilizer is a little larger than that produced by irrigation water, although under the conditions of Experiment I, irrigation was 2.5 to 3.0 times as effective as were the fertilizer treatments used in that experiment. It seems probable that an insufficient amount of irrigation water was added to the plots in Experiment II to permit its maximum effect.

SUMMARY AND CONCLUSIONS

1. The historical background and the application of the percentage yield concept of crop response to soil nutrients are discussed.

2. Field experiments were carried out to determine to what extent the percentage yield concept could be applied to the effect of irrigation water on the yield of dry matter of a grass-clover mixture and of immature oats.

3. Experiments in 1948 failed to indicate the validity of the percentage yield concept as applied to the effect of irrigation water on the growth of grass-clover mixture. However, a close agreement was obtained in the experiment of 1949 between the magnitude of the response of oats due to irrigation water and that predictable by the percentage yield concept.

4. The response to irrigation water was three times as great as to fertilizer in the 1948 experiment, but it was slightly less than the effect of the fertilizer in the 1949 trials. It is probable that insufficient water was added in the latter experiments to permit its maximum effect.

5. Under the conditions of both experiments, fertilization with superphosphate and potash failed to increase the yields of dry matter unless irrigation water also was added.

6. The experiments described were preliminary in nature and were reported to emphasize the value of quantitative studies of the response of crops to irrigation water.

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THE STABILITY OF VARIOUS IODINE COMPOUNDS IN SALT BLOCKS[1]

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In a previous publication (2) the stability of iodine in block salt was investigated. Iodine was added in the form of potassium iodide and it was shown that this was unstable except in dry dark storage.

This paper reports an investigation of the stability of dithymol diiodide, potassium iodate and iodide complex in block salt. Dithymol diiodide is an organic compound having the formula $(C_6H_2.CH_3.OI.C_3H_7)_2$. It has been shown to be physiologically available (1). It is insoluble in ordinary solvents but is soluble in carbon tetrachloride. The iodide complex is an organic compound supplied by Merck & Co., Ltd., for investigation. It contains 7.5 per cent nitrogen and about 40 per cent iodine.

All salt blocks were made up by Canadian Industries Limited and supplied to the Chemistry Division for testing.

All blocks were made up in 50 lb. size. Conditions to which the blocks were subjected were similar to those described in the earlier publication (2).

EXPERIMENTAL

The following salt mixtures were investigated:

Dithymol Diiodide Salt

Salt		Salt	
Dithymol Diiodide	0.033 per cent	Dithymol Diiodide	0.033 per cent
		Iron Oxide	0.1 per cent

Iodate Salt

Salt		Salt	
Potassium Iodate	0.0253 per cent	Potassium Iodate	0.0253 per cent
		Iron Oxide	0.1 per cent

Iodide Complex

Salt		Salt	
Iodide Complex	12.5 oz. per ton	Iodide Complex	12.5 oz. per ton
		Cobalt Carbonate	6.4 oz. per ton
		Ultramarine blue, standard colour	

METHODS OF ANALYSIS

1. *Dithymol Diiodide*

The salt was extracted 4 times with approximately 100 ml. carbon tetrachloride, and the combined extracts evaporated. Saturated sodium carbonate solution was added to the extract, evaporated to dryness and ashed at 500°. The ash was taken up in water, transferred to a separatory funnel and iodine liberated with 5 ml. each of sodium nitrite (5 per cent) followed by sulphuric acid (5 per cent). Free iodine was extracted with

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carbon tetrachloride and the colour intensity determined in a Klett-Summerson colorimeter. Recovery of known additions of dithymol diiodide to iodine-free salt was quantitative by this procedure.

2. *Potassium Iodate*

Iodine determinations of salt containing potassium iodate were made by dissolving 25 grams of salt in water. A small crystal of KI was added, the mixture was acidified with 10 per cent hydrochloric acid in a separatory funnel. The liberated iodine was extracted with carbon tetrachloride and determined as above. Iodine is liberated in accordance with the following equation: $KIO_3 + 5\ KI + 6\ HCl \rightarrow 6\ KCl + 3\ I_2 + 3\ H_2O$.

3. *Iodide Complex*

Iodine in iodide complex was determined by making a paste of the salt with saturated sodium carbonate solution. The paste was taken to dryness on a water bath, ashed at 500° and again made into a paste with water. This paste was extracted four times with 95 per cent ethyl alcohol. The alcohol was evaporated on the water bath and the residue taken up in water. The iodine was liberated in a separatory funnel with sodium nitrite and sulphuric acid and extracted with carbon tetrachloride.

TABLE 1.—IODINE CONTENT OF SALT BLOCKS*

Dithymol Diiodide			Potassium Iodate		
Date of sampling	No Fe_2O_3	With Fe_2O_3	Date of sampling	No Fe_2O_3	With Fe_2O_3
1948			1949		
2/6	24	20	13/5	18	19
12/6	18	13	27/5	16	16
22/6	17	11	10/6	16	16
2/7	10	8	12/7	14	14
12/7	12	10			
22/7	12	10			
4/8	11	11			
16/8	12	12			
8/9	11	10			
20/10	8	9			
14/12	12	7			

* Parts per 100M.

TABLE 2.—IODINE CONTENT OF STALL-FED SALT

Date of Sampling	Salt + Dithymol Diiodide	Salt + Potassium Iodate
1949	*Iodine, parts per 100M*	
18/1	10	18
24/3	13	16
13/5	10	14

RESULTS

The original 50-lb. blocks were sawn into 10-lb. pieces. These were exposed to conditions designed to correspond to exposure in pasture and sampled at intervals. The results with dithymol diiodide and potassium iodate are shown in Table 1, where the first date of sampling indicates pre-exposure values. No data are given for the iodide complex because ten days after exposure the iodine had dropped to 4 parts per 100 thousand for salt + iodide complex and to 0 for salt + iodide complex + cobalt carbonate. Further investigation appeared unwarranted.

In January 1949, after having been in dark, dry storage for 19 months, 50-lb. blocks of salt containing dithymol diiodide and potassium iodate were placed in the manger of a steer at the Animal Nutrition Building. They remained until the blocks were all consumed. Iodine determinations were made at intervals of two months. Results are shown in Table 2.

Both dithymol diiodide and potassium iodate are relatively stable when salt is stored in dark, dry storage.

Availability of Iodine Fed as Iodate to Live Stock

Potassium iodate was fed to sheep at different levels for a period of eight days. The urine was collected for the last four days and the iodine content was determined Results are shown in Table 3.

Potassium iodate was fed to two pigs at a level of 0.25 gm. for a preliminary period of four days and a further period of eight days. During the eight-day period, urine was collected on a twenty-four hour basis, so that any one collection, selected for analysis, would correspond to an intake of 0.25 gm. of potassium iodate. Twenty-four hour samples of urine from each animal were analysed on each of three days. During this time the amount of iodine fed was 0.445 gm. Iodine recovered in the urine was 0.207 and 0.202 gm. This is an average recovery of 45.9 per cent for both animals.

In the analytical procedure, due to the considerable quantity of organic matter present, it was considered possible that iodate might be reduced to iodide according to the reaction $KIO_3 + C \rightarrow KI + 3\ CO$. To investigate this point 0.1 gm. of KIO_3 was added to 100 ml. of sheep urine and iodine determinations were made. The quantity of iodine in the urine originally was negligible. The urine was evaporated to dryness and ashed to a gray black ash. The ash was taken up in water, transferred to a separatory

TABLE 3.—URINE EXCRETION OF IODINE IN SHEEP

Animal No.	Gm. Iodine Fed as KIO_3	Gm. Iodine Recovered	Per cent Iodine Recovered
			%
1	0.5932	0.0469	7.9
2	1.1868	0.0261	2.2
3	1.7804	0.1600	9.0
4	2.3740	0.9855	41.5

funnel, acidified and iodine was extracted with carbon tetrachloride; 0.1 gm. KIO_3 contained 0.059 gm. iodine; 0.0425 gm. or 70 per cent of the iodine added was recovered, indicating that KIO_3 was reduced to potassium iodide.

A further test of availability of iodine from potassium iodate was made by feeding iodate to sheep and swine and collecting the urine. Fresh urine samples were extracted with carbon tetrachloride to remove any colouring matter which was soluble in carbon tetrachloride. The urine was then acidified with 10 per cent HCl. If both potassium iodate and potassium iodide were present, iodine would be liberated according to the reaction:

$$KIO_3 + 5\ KI + 6\ HCl \rightarrow 6\ KCl + 3I_2 + 3\ H_2O$$

No iodine was recovered by this procedure, but when sodium nitrite was added iodine was released.

It was concluded that iodine fed as iodate was available to the animal because it was found in the urine as potassium iodide.

SUMMARY AND CONCLUSIONS

1. Potassium iodate and dithymol diiodide and Merck iodide complex as sources of iodine in salt blocks were tested under practical feeding conditions.

2. Blocks containing potassium iodate and dithymol diiodide retained a high percentage of their original iodine content when subjected to outside exposure and when fed in a manger, to steers. Iodide complex rapidly lost all iodine when subjected to outside exposure.

3. Potassium iodate and dithymol diiodide when used as iodine carriers in salt blocks, would both satisfy the animals' requirements for iodine, from the standpoint of stability.

4. Iodide complex is a very unstable source of iodine in block salt.

5. The iodine in dithymol diiodide is known to be physiologically available to animals, and that of potassium iodate has been shown to be physiologically available to swine and sheep.

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WATER EROSION OF SOIL[1]

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The annual loss of soil through water erosion is one of the more serious problems facing Canadian agriculture to-day.

While extensive, detailed information is not available for the erosion problem in Canada, observations have shown that extensive soil losses have occurred in some districts. In Prince Edward Island, reports indicate that 7.7 per cent of the total area is susceptible to serious erosion. The Upper St. John Valley of New Brunswick and the Eastern Townships of Quebec have lost many tons of top soil through erosion. Soil surveyors have estimated in twenty-four counties of Southern Ontario that an average of 50 per cent of the total area of lands is suffering from moderate to severe erosion. While wind erosion is the major cause of concern in the Prairie Provinces, losses of soil through water erosion are also serious in several areas. Severe losses of soil have occurred on steep, irrigated lands and on over-grazed ranges in British Columbia.

In order to obtain some specific information on water erosion of soil, field experiments were initiated by the Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service, at Ottawa, in the fall of 1944. Phases of the project requiring chemical studies are conducted by the Division of Chemistry, Science Service. The data reported herein represent results obtained from the experiments during the period 1945 to 1949, inclusive.

The soil of the area selected for these experiments has been mapped as a Rideau clay (3). The Rideau clay is a very heavy, moderately drained, stone-free soil, with gently undulating topography. Moderate to severe erosion had occurred on this site prior to the present investigations.

PROCEDURE

Experimental plots one-fortieth (1/40) acre in size representing different management practices were established on both 5 per cent and 10 per cent slopes. The various cropping systems arranged in order of susceptibility to erosion along with plot dimensions are given in Table 1.

The various plots are equipped with a metal trough and catchment tank for the collection of soil and water runoff from any rain. The troughs are located at the bottom of the plots at ground level, with an open side facing the plot. The soil and water runoff is carried from the trough to a catchment tank by means of metal piping. Following each erosive rain the soil and water collected in the tanks is weighed and samples taken for determination of percentage solids in the laboratory. The troughs and tanks are assembled as early as possible in the spring, usually around April 15, and dismantled in the fall at the end of October. A Friez water

[1] Joint contribution from the Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service, and the Division of Chemistry, Science Service. Scientific Contribution No. 189. Division of Chemistry, Science Service.

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TABLE 1.—CROPPING SYSTEMS USED IN EROSION STUDIES AT OTTAWA

Plot numbers	Plot sizes in feet	Per cent slope	Crops and management practices
10–11	72.6 × 15.0	10	Continuous crops of summerfallow, corn—no manure—up and down the slope.
5– 9	72.6 × 15.0	10	Continuous crops of summerfallow, corn, oats, alfalfa and timothy—manured—up and down slope.
20–24	72.6 × 15.0	5	Continuous crops of summerfallow, corn, oats, alfalfa and timothy—manured—up and down slope.
12–15	72.6 × 15.0	10	Corn, oats, alfalfa, alfalfa—manured—rotation up and down slope.
25–28	40.0 × 27.2	5	Continuous crops of corn, oats, alfalfa, and timothy-manured—on contour
1– 4	40.0 × 27.2	10	Corn, oats, alfalfa, alfalfa—manured—rotation on contour.
29–32	40.0 × 27.2	5	Corn, oats, alfalfa, alfalfa—rotation on contour.
16–19	120.0 × 27.2	10	Corn, oats, alfalfa, alfalfa—manured—strip crops in rotation on contour.
33–36	40.0 × 27.2	Level	Corn, oats, alfalfa, alfalfa—rotation on level ground

Note—Rotted manure is applied for the corn crop in the rotation at the rate of 16 tons per acre. In the case of continuous cropping systems, manure is applied every 4 years beginning in 1944.

level recorder is attached to the tank of Plot 5. This allows for measurement of the intensity of runoff during any rain. Records of rainfall during the season are taken by means of a Friez rainfall and intensity recorder.

A study of some of the physical and chemical properties of the soil from the experiment was commenced in the spring of 1946. This phase of the work is divided into two parts: (*a*) samples collected from representative plots, both at the beginning of the experiment, and after it has been in operation for a number of years, will be analysed; (*b*) in the same years that the samples are collected from the plots, samples of the eroded material will be analysed. The purpose of the work is to obtain detailed information about the soil and to determine the effect of erosion on its chemical and physical properties. The results from the first samples, collected in 1946, are discussed here.

Soil samples to a depth of six inches were obtained from plots representative of each of the cropping practices on both the 5 per cent and 10 per cent slopes. On all of the plots except No. 18, where strip-cropping is practised, three samples were taken, one representing the soil near the top of the slope, one the soil half-way down the slope, and one the soil near the bottom of the slope. Four samples were taken from plot No. 18, one from each of the four sections in the plot. During the summer, samples of the eroded material were collected after every rain, and at the end of the season composite samples of the air-dry soil from individual plots were made which represented the total eroded material.

The samples were analysed for pH, moisture, loss on ignition, nitrogen, and the exchangeable bases calcium, magnesium and potassium. The following physical properties were also determined: per cent sand, silt, and clay by the hydrometer method of Bouyoucos (1), colloids by the water-vapour method described by Robinson (6), moisture equivalent by the Briggs and McLane method (2), and the suspension percentage according to the method outlined by Middleton (5). From the results obtained by the physical analyses the ratio of colloids to moisture equivalent, dispersion ratio, and erosion ratio were calculated as described by Middleton (5).

EXPERIMENTAL RESULTS AND DISCUSSION

Chemical and Physical Properties of the Soil

Results of chemical and physical analyses of the soil from the area are shown in Tables 2 and 3, respectively, where averages for three samples from each plot are presented. There was considerable variation in the soil from the different plots. For instance the sand varied from 41.1 per cent to 19.2 per cent, the clay from 50.3 per cent to 33.6 per cent and the nitrogen from 0.14 per cent to 0.26 per cent. The soil from most of the plots was slightly to moderately acid, which was expected with Rideau clay (3) (4); it was surprising, however, that the soil from two of the plots was slightly alkaline. The colloid to moisture equivalent, dispersion and erosion ratios, which Middleton (5) suggests may be used to indicate the erodibility of a soil, all showed that the soil may be classified as highly erosive. The colloid to moisture equivalent ratio varied from 0.64 to 0.87, and Middleton proposed a limit of 1.5 below which a soil may be classified as erodible. The dispersion ratio (22.4 to 35.2) and the erosion ratio (31.5 to 51.0) found were well above 15 for the former and 10 for the latter suggested by Middleton as the upper limits for non-erosive soils.

TABLE 2.—PHYSICAL PROPERTIES OF THE SOIL

(Averages from three positions in each plot)

Plot No.	Sand	Silt	Clay	Colloids	Moisture equivalent	Suspension percentage	Colloid to moisture equivalent ratio	Dispersion ratio	Erosion ratio
	%	%	%	%		%			
1	19.2	33.7	47.1	22.6	32.0	18.1	0.71	22.4	31.5
3	20.7	35.0	44.2	24.6	33.3	23.5	0.74	29.7	40.1
6	23.7	33.4	42.9	20.9	31.2	22.9	0.67	30.0	45.8
8	24.8	31.7	43.5	21.8	31.5	26.5	0.69	35.2	51.0
11	27.8	27.1	42.1	19.3	29.6	22.0	0.65	31.8	48.9
12	23.2	29.5	47.3	21.9	31.3	24.1	0.70	31.4	44.9
14	22.4	32.1	45.5	22.1	31.7	26.0	0.70	33.5	47.9
18	30.8	29.8	39.4	23.1	33.2	21.2	0.70	31.6	45.1
21	27.7	30.1	42.2	20.5	31.3	22.4	0.65	31.0	47.7
23	30.7	25.7	43.5	21.6	31.3	21.4	0.69	30.9	44.8
25	41.1	24.6	33.6	18.5	28.8	14.5	0.64	24.9	38.9
27	26.8	37.7	35.5	21.3	32.1	22.9	0.66	31.3	47.4
29	31.5	26.2	42.3	25.3	33.0	21.2	0.77	30.9	40.1
31	21.3	28.4	50.3	29.6	34.1	25.9	0.87	32.9	37.8

TABLE 3.—CHEMICAL ANALYSES OF THE SOIL

(Averages from three positions in each plot)

Plot No.	pH	H_2O	Loss on ignition	Nitrogen	Exchangeable		
					Ca	Mg	K
		%	%	%	%	%	%
1	6.5	3.3	5.7	0.17	0.30	0.030	0.007
3	7.1	3.3	6.1	0.19	0.38	0.028	0.010
6	7.4	2.4	5.7	0.18	0.25	0.035	0.031
8	6.5	2.7	5.5	0.14	0.29	0.042	0.009
11	6.3	2.8	4.9	0.15	0.23	0.030	0.007
12	6.5	3.1	5.1	0.16	0.29	0.043	0.010
14	6.4	3.2	5.6	0.18	0.29	0.042	0.010
18	6.1	3.7	7.4	0.24	0.28	0.033	0.012
21	6.0	3.4	5.3	0.18	0.24	0.034	0.010
23	5.9	3.4	5.7	0.19	0.24	0.051	0.012
25	6.0	2.7	6.4	0.22	0.26	0.034	0.013
27	6.0	2.9	7.2	0.26	0.26	0.037	0.007
29	6.0	3.6	7.0	0.21	0.24	0.042	0.008
31	6.0	3.8	6.1	0.16	0.31	0.050	0.006

The position on the slope from which the samples were taken appeared to have a marked influence on the composition of the soil in many instances. This was especially true for the plots on the 10 per cent slope where a definite pattern was apparent. The latter point is illustrated in Table 4, where the average values for each position on the 10 per cent slope for all of the plots except No. 18 are shown.

The table shows that the soil at the bottom of the slope contained more organic matter and was of a lighter texture than the soil at the top. This may indicate a loss of the surface soil by erosion during which the clay subsoil has become exposed at the top of the slope while at the lower end this loss has not occurred; or—what is more likely—the loss at the bottom of the slope has been compensated for by soil moving down from farther up the slope. On the more gentle 5 per cent slope, results, not presented here, showed that the variation within plots was apparently no greater than the variation between plots. Furthermore, in some of the latter plots the soil at the bottom of the slope contained more sand and organic matter than the soil at the top, while in others the reverse was true.

TABLE 4.—EFFECT OF POSITION ON THE 10 PER CENT SLOPE ON SOME OF THE CHARACTERISTICS OF THE SOIL*

Position on slope	Loss on ignition	Nitrogen	Exchangeable Mg	Sand	Clay	Erosion ratio
	%	%	%	%	%	%
Top	4.8	0.12	0.047	14.7	55.4	32.8
Middle	5.7	0.18	0.035	23.0	43.9	51.9
Bottom	6.0	0.20	0.026	31.7	34.7	54.1

* Average of the results from 7 plots

Precipitation at Experimental Site

At the Central Experimental Farm, Ottawa, the average annual precipitation for the last sixty years was 34.57 inches. The monthly precipitation for the seven months April to October of each year since the experiment began, the average for each month of this period, and the long-time average precipitation for these months, are given in Table 5.

The 5-year average precipitation for the growing seasons 1945 to 1949 was 23.32 inches, which was slightly above the 60-year average of 21.04 inches. The growing seasons of 1945, 1946 and 1947 could be classed as relatively wet periods while the corresponding months of 1948 and 1949 were comparatively dry. In the growing seasons of 1945, 1946, and 1947 at least five of the seven months received more than average rainfall. In contrast, the season of 1948 and 1949 had at least four months in which the monthly precipitation was below average.

TABLE 5.—PRECIPITATION, APRIL TO OCTOBER, CENTRAL EXPERIMENTAL FARM, OTTAWA
(In inches)

Months	Years of record					Average 1945-1949	Average 1889-1949
	1945	1946	1947	1948	1949		
April	4.14	2.88	3.66	2.12	3.08	3.18	2.40
May	5.39	2.92	5.41	2.84	1.91	3.69	2.84
June	2.95	4.81	4.08	2.60	2.43	3.37	3.41
July	2.91	2.86	5.15	2.97	2.78	3.33	3.60
August	4.94	4.34	1.24	2.79	3.89	3.44	3.11
September	5.96	3.27	4.67	1.24	3.56	3.74	3.00
October	3.02	4.86	0.59	2.84	1.56	2.57	2.68
Total, April-October	29.31	25.94	24.80	17.40	19.21	23.32	21.04

Runoff as Affected by Various Factors

Amount and Intensity of Rainfall

The variation in precipitation from year to year has resulted in a distinct difference in the total runoff in different years. In 1945, 1946 and 1947 there was above-average precipitation during the growing season and erosion losses were relatively severe. On the other hand, in 1948 and 1949, the precipitation for similar periods was below average and runoff losses were much lower. The variation in runoff in different years may be illustrated by the results obtained on a corn plot where tillage and seeding operations were carried on, up and down a 10 per cent slope. During the 5-year period 136.4 tons of soil per acre were lost from this plot. Approximately 90 per cent of this amount was removed in the years 1945, 1946, and 1947. In 1946 when erosion was particularly severe a loss of 77.5 tons of soil per acre was recorded for this plot.

While the total precipitation over a given period such as a growing season is of interest, the distribution and intensity of the rainfall have a more pronounced effect on the extent of erosion losses. The losses of soil occurring from rains of various intensities, from a plot of corn seeded up and down a 10 per cent slope, are presented in Table 6.

TABLE 6.—THE EFFECT OF INTENSITY OF RAINFALL ON SOIL EROSION AT OTTAWA

(Plot 6—Corn, up and down a 10 per cent slope)

Date of rain	Rainfall	Duration of rainfall	Soil losses per acre
	Inches		Tons
June 17, 1946	2.90	60 minutes	53.5
July 22, 1946	0.50	10 minutes	6.5
July 17, 1947	1.98	3 showers, each 30 minutes	18.2
September 22, 1947	1.29	24 hours	1.4

The data indicate that heavy "flash" rains falling in a few hours produce considerably more runoff than a moderate rain over an extended period of time.

Degree of Slope

A comparison of the runoff on 10 and 5 per cent slopes, as presented in Table 7, shows that soil losses on the 10 per cent slope were more than double those occurring on the 5 per cent slope.

TABLE 7.—A COMPARISON OF RUNOFF ON TEN AND FIVE PER CENT SLOPES

Period of measurement	Crop—up and down slope, manured	Total runoff for period			
		10 per cent slope		5 per cent slope	
		Soil per acre	Water per acre	Soil per acre	Water per acre
		Tons	Tons	Tons	Tons
1946-1949	Continuous summerfallow	132.2	854.7	52.4	519.6
1945-1949	Continuous corn	136.4	1342.4	63.7	1208.2

FIGURE 1. General view of some of the catchment tanks of the soil erosion experiments at Ottawa.

Cropping Practices

(1) Vegetative Cover

The relative effectiveness of different crops in providing cover and in reducing runoff on a 10 per cent slope is shown by the results in Table 8.

TABLE 8.—EFFECT OF VEGETATIVE COVER ON RUNOFF ON A 10 PER CENT SLOPE
(Cultivation up and down the slope)

May-October, 5-year average, 1945-1949

Crop	Soil losses per acre	Water losses	
		Per acre	As per cent of actual rainfall recorded at time of runoff
	Tons	Tons	%
Summerfallow	26.5	213	25.8
Corn	27.3	268	32.5
Oats	0.7	47	5.7
Alfalfa	0.1	22	2.7
Timothy*	0.2	3	0.6

* Figures for timothy represent only the year 1946, as no runoff has occurred under this cover, since that time

The soil losses from plots in summerfallow and corn were very high as compared to the relatively low losses under a cover of alfalfa or timothy. In addition, high water losses were recorded from the corn and summerfallow plots. Hay and grain crops have provided sufficient cover to retain most of the rainfall.

(2) Use of Farm Manure

The effect of farm manure in reducing runoff was evaluated on summerfallow and corn plots located up and down a 10 per cent slope. A comparison of the runoff occurring on these plots, one receiving no manure and the other with manure applied at the rate of 16 tons per acre every 4 years, is shown for the period 1945 to 1949 in Table 9. These results indicate that the application of farm manure has reduced runoff to the extent of 26 tons of soil and 277 tons of water per acre on the summerfallow plot, and 35 tons of soil and 150 tons of water per acre on the corn plot.

TABLE 9.—THE USE OF FARM MANURE IN REDUCING RUNOFF ON A 10 PER CENT SLOPE

Crop grown continuously	Total losses—1945 to 1949			
	Manure		No manure	
	Soil per acre	Water per acre	Soil per acre	Water per acre
	tons	tons	tons	tons
Summerfallow	132.2	1067.8	158.9	1345.3
Corn	136.4	1342.4	172.2	1492.8

(3) Contour Cropping

Contour practices have reduced runoff. This is illustrated in Table 10 which shows the losses of soil and water for contour methods as compared with up and down the slope cultivation for corn on a 10 per cent slope. During the 5-year period, where the contour method was practised, the average loss of soil was only 58.5 per cent and the loss of water 70.4 per cent of the amount recorded for the plots tilled up and down the slope. In 1946, a year when runoff was high, the loss of soil per acre on the corn plot, seeded up and down the slope, was 20.5 tons greater than that occurring where corn was planted on the contour.

TABLE 10.—COMPARISON OF RUNOFF FOR CONTOURING AND UP AND DOWN THE SLOPE CROPPING WITH CORN ON A 10 PER CENT SLOPE

Year	Contour		Up and down the slope	
	Soil per acre	Water per acre	Soil per acre	Water per acre
	Tons	Tons	Tons	Tons
1945	5.0	176.0	7.7	336.6
1946	28.8	273.4	49.3	296.2
1947	0.1	7.6	0.9	34.6
1948	0.4	13.3	0.6	8.7
1949	0.4	21.2	0.3	23.4
5-year average	6.9	98.5	11.8	139.9

(4) Strip Cropping

The effect of hay and grain crops in providing good vegetative cover for soils and in reducing runoff has already been discussed. When the cultivated crops were grown across the slope in conjunction with crops which provided adequate vegetative cover, the latter crops were effective in reducing runoff from the cultivated areas located above them. Runoff losses on a 10 per cent slope for a 4-year rotation of corn, oats, alfalfa, and alfalfa, in strips 30 feet in width, are given in Table 11. It should be noted also that the data represent the total losses for a 4-year period indicating that losses of soil from strip cropping have been relatively light.

TABLE 11.—EFFECT OF STRIP CROPPING IN REDUCING RUNOFF OF SOIL

Position of crop—top to bottom of slope	Total soil losses 1946-1949 per acre
	Tons
Oats, alfalfa (1), alfalfa (2), corn	4.26
Alfalfa (1), alfalfa (2), corn, oats	0.61
Alfalfa (2), corn, oats, alfalfa (1)	0.73
Corn, oats, alfalfa (1), alfalfa (2)	0.51

Eroded Material

The effect of cropping practices on the composition and physical properties of the eroded material could not be determined because it was only with those practices that caused severe erosion (cultivated crops up and down the slope) that it was feasible to collect sufficient material for

detailed study. However, there were three plots where both soil samples and eroded material were analysed. Table 12 is a summary showing the average results obtained for the soil from the plots and those for the corresponding eroded material. The suspension percentages were higher for the eroded material than for the soil from the plots and for this reason the dispersion and erosion ratios were similarly higher. With the exception of these differences, the eroded material was apparently quite similar to the soil samples obtained from the corresponding plots, where severe erosion occurred.

Table 12.—Some physical axd chemical properties of eroded material compared with those of the soil from the plots

Plot No.	Sample	Sand	Clay	Colloids	Susp. percentage	Moisture equiv.	Disp. ratio	Erosion ratio	pH	Nitrogen	Exchangeable Ca
		%	%	%	%					%	%
6	Soil	23.7	42.9	20.9	22.9	31.2	30.0	45.8	7.4	0.18	0.25
	Eroded material	18.8	46.0	22.3	39.4	35.5	48.5	78.6	7.3	0.19	0.19
11	Soil	27.8	42.1	19.3	22.0	29.6	31.8	48.9	6.3	0.15	0.23
	Eroded material	27.0	42.0	19.8	38.2	30.1	57.0	79.2	6.0	0.16	0.20
21	Soil	27.7	42.2	20.5	22.4	31.3	31.0	47.7	6.0	0.18	0.24
	Ero ed material	22.0	45.0	22.3	44.5	35.8	57.0	91.9	6.2	0.22	0.19

Effect of Erosion Control Measures on Crop Yields

As this experiment has been in progress for only a few years, the yields of crops produced under the various erosion control measures should not be regarded as conclusive although certain trends are apparent. The average yields of corn, oats and alfalfa, grown continuously and in a 4-year rotation, under different management practices on a 10 per cent slope, as well as those for a similar rotation on level land, are presented in Table 13.

Table 13.—Average yields of corn, oats and alfalfa produced under various erosion control measures

Cropping system	Corn 1946-1949	Oats 1946-1949	Alfalfa 1947-1949	Alfalfa 1947-1949
	tons	tons	tons	tons
Four-year rotation on the level ground	10.90	52.6	3.01	3.30
Four-year rotation on the contour	8.96	43.4	2.59	2.93
Four-year rotation up and down the slope	6.97	36.8	3.01	4.95
Continuous cropping up and down the slope	6.16	30.9	—	3.46

The average yields of corn and oats have been higher where grown on the level. Growing corn and oats in a rotation on the contour has produced an average of 8.96 tons of corn and 43.4 bushels of oats per acre as compared with 6.97 tons of corn and 36.8 bushels of oats where grown up and down the slope. The yields of both crops up and down the slope have been

higher when grown in a rotation than when grown continuously. Excellent yields of alfalfa have been produced under all the various practices, considering the severe erosion losses for the area during the past, as well as during the period of experimentation.

SUMMARY AND CONCLUSIONS

The results of erosion experiments on a Rideau clay soil at the Central Experimental Farm, Ottawa, for the years 1945 to 1949, inclusive, have been presented. The runoff losses and the physical and chemical properties of the soil and the eroded material are discussed.

Examination of the rainfall data for the various growing seasons showed the importance of the intensity of the rainfall, rather than the total precipitation as a factor affecting soil erosion.

The fact that severe losses of soil and water occurred under certain cropping practices agrees with the results obtained for Middleton's erosion ratios.

The results of the experiments have shown that the maintenance of a good vegetative cover and the use of farm manure can reduce soil and water losses materially. The growing of corn, oats and hay crops in rotation on the contour, or in strips across the slope, also helps to reduce erosion losses.

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DIFFERENTIAL DAMAGE TO BARLEY VARIETIES BY GRASSHOPPERS[1]

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INTRODUCTION

Grasshoppers cause important losses to cereal crops in Western Canada. Damage may occur at any time during the growth of the crop, but it usually occurs either when the crop is in the seedling stage or after heading. The former is commonly referred to as seedling damage and the latter as head dropping. Heavy seedling damage results from the feeding of grasshopper nymphs in outbreak numbers. The entire crop over wide areas may be destroyed. Head dropping results from feeding by the adult grasshoppers on the upper internode, usually just below the spike. Complete destruction of the crop may result from a winged invasion of large numbers. More frequently moderate damage occurs as a result of a small grasshopper population that has existed in the field all season.

Damage in the seedling stage can usually be controlled by the use of insecticides. The spraying or baiting of field margins at the time of invasion is relatively inexpensive and is usually very effective in destroying the young grasshoppers. Damage to the nearly mature crop is much more difficult to control. The invading insects spread rapidly throughout the field and can cause heavy losses even though present in small numbers. They can be destroyed by spraying or baiting but such action is necessarily confined to field margins because of the cost of the insecticide and the damage to the maturing crop by the passage of spraying equipment.

One possible method of reducing damage by grasshoppers would be the use of resistant varieties, if such could be demonstrated to exist.

In the course of testing cereal varieties at the Dominion Experimental Station, Swift Current, Saskatchewan, natural infestations of grasshoppers occasionally caused damage. Wide varietal differences in the amount of grasshopper damage were noted, especially among barley varieties. Consequently, in 1944 it was decided to investigate the reaction of barley varieties to grasshopper attack. Tests were conducted from 1944 to 1947 to determine whether there were consistent differences in the amount of damage suffered by these varieties. The relationship of time of maturity and protein content to amount of damage was also studied. In further tests the reaction of hybrid lines from a cross between a resistant and a susceptible variety was studied in relation to various agronomic characters.

This paper summarizes the results that were obtained.

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LITERATURE REVIEW

Comprehensive reviews on the resistance of plants to insect damage have been published recently (22, 27). It is proposed to refer only to that literature dealing specifically with grasshoppers, and to mention other crop-insect relationships in the discussion of the results of the present study.

It is a common belief that grasshoppers are a menace to any and all crops, although the literature contains scattered references to the contrary. Ball (2) noted that of 250 species of *Orthoptera* in Arizona the majority are either beneficial or harmless, and are extremely specific in their food habits. Several investigators (20, 23, 29), and more recently Brunson and Painter (7), have recorded wide differences in the amount of grasshopper damage suffered by corn and sorghum. Brunson and Painter noted several instances in which corn in one field was eaten to the ground, whereas sorghum in an adjacent field was practically uninjured. No explanation of this preference for corn was offered by the authors, but it may be a specific characteristic of certain American *Acrididae*, since Uvarov (29) records an Asiatic species that feeds chiefly on sorghums.

Isley (16) studied the interrelationship of 150 species of grasses, forbs, garden and crop plants with 40 species of *Acrididae* in Texas. He concluded that vigorous individuals will starve in the presence of abundance if the particular host species are not present.

Criddle (9) found that whereas some plants, for example *Agropyron Smithii*, are palatable to a great many grasshoppers, others, such as *Setaria viridis*, are rarely touched by these insects.

Mail (20) reported an instance in which half-grown nymphs of *Melanoplus bivittatus* (Say) and *M. differentialis* (Thos.), released in a greenhouse containing 26 kinds of plants, attacked only grapefruit and palm plants, which they damaged severely. The palm plants were hard and stringy.

Andrewartha (1) studying the significance of grasshoppers in relation to soil conservation in Australia, recommended the use of *Atriplex vesicarium*, as grasshoppers will not eat it.

Differences in the amount of damage suffered by various cereal crops have been noted on several occasions. Jones (18), in 1937, observed that two varieties of durum wheat, grown in randomly replicated plots, were completely stripped by a heavy infestation of grasshoppers, whereas 100 plots of spring and winter wheat in the same test were uninjured. Smith (25) noted that, in the severe grasshopper infestation of 1938 in North Dakota, the most damage, in descending order, was in barley, oats, wheat, corn and sorghum. Riley (23), in discussing the feeding habits of the Rocky Mountain locust, listed corn, wheat, rye and coats in that order of preference.

That such specificity in the feeding habits of grasshoppers should extend to varieties of crops is not surprising. In studying the resistance of corn varieties to grasshopper attack, several investigators (5, 14, 21) have reported "Amargo" maize to be highly resistant. Marchioni (21)

was able to select hybrid lines from a cross between "Amargo" and a susceptible variety that were as resistant as the resistant parent. Bredemann (4) attributes the resistance of "Amargo" to the dense pubescence of this variety.

Brunson and Painter (7) obtained outstanding instances of differential damage among corn varieties, top crosses and hybrids grown in Kansas. It is their opinion that neither the gregarious instincts of the grasshoppers, nor differences in maturity of the tested strains were of importance in determining the differential injury noted. As a rule, the varieties and inbred lines showing the most resistance originated in areas where grasshoppers are a natural element of the environment. It was suggested, therefore, that natural selection operating in the development of adapted varieties has tended to intensify resistance to grasshoppers in such varieties.

Hume (15) found that varieties of dent corn suffered more grasshopper damage than did varieties of flint corn.

Hermann and Eslick (12) reported wide differences in the amount of damage sustained by 405 selections from 28 species of grasses exposed to the attack of four economic species of grasshoppers. These differences were equally evident between selections within a species and between species. They concluded that, if the inheritance of a selection influences its susceptibility to attacks by grasshoppers, it may be possible to select strains of grasses which will be more highly resistant than any now produced.

Clark (8) reported Ceres wheat to be less severely damaged by grasshoppers than other varieties grown in North Dakota.

Smith (25) noted wide differences in the amount of damage caused by Lesser Migratory grasshoppers feeding on varieties of spring wheat. He established a positive correlation between the amount of grasshopper damage and stem rust infection among the varieties tested.

Jacobson and Farstad (17) in a study of 41 varieties of spring wheat found distinct varietal differences in the number of heads cut off by grasshoppers.

Marked differences in the reaction of wheat varieties to grasshopper damage as judged by the number of heads dropped has also been reported by Hehn and Grafius (11). They established a very strong negative correlation between the amount of mechanical tissue in the hypodermal region of the culm in sections taken one centimeter below the peduncle and the percentage of heads clipped. Selection of lines with an abundance of mechanical tissue one centimeter below the peduncle is suggested by these authors as a criterion for isolating lines of spring wheat that are highly unpalatable to grasshoppers.

Litzenberger (19) found that Compana and Glacier barley were more resistant to grasshoppr attack than Horn or Trebi.

VARIETAL TESTS

Materials and Methods

Barley varieties were grown in replicated tests at several locations during each of the four years 1944-1947. The numbers of varieties used and the locations of the test plots are shown in Table 1. The plots used were single rows spaced one foot apart. In 1944 they were five feet long;

in 1945 and 1946, a rod long; and in 1947, ten feet long. In all tests six replications were used. The plots were arranged as randomized blocks in 1944 and 1945, in a 7 × 6 rectangular lattice in 1946, and as a triple lattice repeated in 1947. In 1947 there were hybrid lines included in the test in addition to the varieties under discussion.

The damage suffered by these tests resulted from naturally occurring populations of grasshoppers. Such populations were composed of varying percentages of several species, as shown in Table 1. The percentage of species present at Burdett in 1947 was determined by R. M. White, Entomologist, Field Crop Insect Laboratory, Lethbridge. The percentage of species present at the other tests conducted in 1947 were determined with reasonable accuracy, whereas in the remainder of the tests the determinations were only very rough approximations.

The locations for the tests were chosen on the basis of forecast information secured from the Officers of the Field Crop Insect Laboratories, Science Service, Department of Agriculture, located at Saskatoon and Lethbridge. The density of the grasshoppers per unit area was not estimated previous to 1947. In that year the estimated number per square yard was eight at Gravelbourg and Shaunavon, and fifteen at Herschel and Burdett.

The damage to barley reported in this paper refers to the percentages of heads dropped, unless otherwise stated. Single estimates of damage were made on each plot, except for tests grown in 1945, when the average of two independent estimates was recorded. Different individuals estimated damage in each of the years. In 1944, estimates of damage at two locations were made at weekly intervals from the beginning of infestation until the crop was mature. Estimates of damage in subsequent tests were made only when the crop was well matured.

In the statistical analysis of the data the percentage figures were converted to $\sin^2\theta$, as recommended by Bliss (3). Before conversion, one unit was added to each percentage figure to avoid zero readings. In calculating the analyses of variance, correlation coefficients, etc., Goulden (10) was used as a guide.

Results

The mean percentage grasshopper damage, the range of damage between varieties, and the statistical significance of varietal differences in each test are presented in Table 1. Twelve tests were conducted and significant varietal differences were established in nine of these tests.

In the remaining three tests the following conditions prevailed. At Shaunavon, in 1946, only a few grasshoppers were present. Damage up to 40 per cent occurred in a few very susceptible varieties but most of the varieties had zero readings. Statistically significant differences could probably have been established but it was not considered worth-while to analyse the data. At Cabri, in 1946, no grasshoppers were present and, consequently, no differences in damage could be established. The third test at which differences were not established was at Piapot in 1944. At this test a heavy grasshopper population was present before the crop emerged. As the plants emerged they were kept eaten to the ground until, eventually, all growth ceased.

TABLE 1.—SUMMARY OF LOCATION, TYPE OF DAMAGE, PREDOMINANT SPECIES AND RESULTS OF BARLEY VARIETAL TRIALS FOR GRASSHOPPER REACTION

Station	Year	No. var. tested	Predominant species	Type of damage	Mean damage	Range of damage	F value[3]
					%	%	
Swift Current	1944	37	*M.m. mexicanus*[1]	Head dropping	63	18–93	6.57
Sask. Landing	1944	37	*M.m. mexicanus*	Head dropping	53	20–82	5.00
Carmangay	1944	37	*M.m. mexicanus*	Head dropping	87	22–100	8.35
Piapot	1944	37	*M.m. mexicanus*	Seedling	100	—	—
Nobleford	1945	36	*M.m. mexicanus*	Head dropping	30	1–82	26.92
Cabri	1945	41	*M.m. mexicanus* 40% *M. bivittatus* 40% *M. packardi* 20%	Feeding began before heading Susceptible plants completely destroyed	53	1–100	69.09
Cabri	1946	42	—	None	—	—	—
Shaunavon	1946	42	—	Slight head dropping	—	—	—
Shaunavon	1947	42	*M. bivittatus* 45% *M.m. mexicanus* 18% *C. pellucida*[2] 37%	Head dropping	22	1–92	32.81
Gravelbourg	1947	42	(as Shaunavon 1947)	Head dropping	20	2–83	16.99
Herschel	1947	42	*C. pellucida* 80% *M.m. mexicanus* 10% *M. bivittatus* 10%	Head dropping	87	61–99	11.07
Burdett	1947	42	*M.m. mexicanus* 90% *M. bivittatus* 5% *M. packardi* 5%	Head dropping	91	20–100	7.75

[1] *Melanoplus mexicanus mexicanus.*
[2] *Camnula pellucida.*
[3] All values significant at the 1 per cent point.

In eight of the nine tests in which varietal differences were established, damage consisted of head dropping. In these tests appreciable feeding did not occur until the crop was headed. In the remaining test, Cabri 1945, feeding began when the varieties were in the shot blade and continued until they were mature. Susceptible varieties were eaten to the ground and all new growth destroyed whereas resistant varieties grew and matured normally except for leaf stripping. Intermediate reactions were also obtained. The varietal differences in this test were the most striking of any that were recorded.

An analysis of the estimates of damage taken at various dates at Swift Current and Saskatchewan Landing in 1944 showed no significant interaction between varieties and dates at either station.

It was not possible to make a complete analysis of all varieties at all stations. The varieties changed from year to year and sometimes varieties had to be discarded because one or more plots were lost due to rodent or other injury. There were 32 varieties on which complete data for eight of the nine tests were available. Results were available from 26 of the varieties at the ninth test, Nobleford 1945. A summary of these data are presented in Table 2.

An examination of these data shows a considerable test-variety interaction. This was particularly true at Herschel. In this test the reaction of many varieties was in disagreement with the results from other tests.

TABLE 2.—MEAN PER CENT HEAD DROPPING BY GRASSHOPPERS ON BARLEY VARIETIES GROWN AT VARIOUS STATIONS AND MEAN OF ALL STATIONS CALCULATED FROM VALUES CONVERTED TO $SIN^2\theta$

Variety	C.A.N.	Swift Current 1944	Sask. Land. 1944	Carm. 1944	Cabri 1945	Gravel. 1947	Shaun. 1947	Burd. 1947	Hersch. 1947	Noble. 1945	Mean less Noble.	Converted mean*
Can. Thorpe	816	87	55	100	100	56	91	100	81	82	84	71.5
Gordon	833	93	73	100	100	42	60	100	97	72	83	71.8
O.A.C. 21	734	85	68	100	94	35	58	100	99	74	80	68.6
Glabron	718	80	82	100	93	42	50	98	98	58	80	67.8
Wis. Ped. 38	758	90	72	99	93	40	44	100	88	67	78	66.2
Nobarb	1022	80	58	100	97	36	56	99	89	65	77	65.4
Horn	—	73	61	100	98	43	43	99	94	47	76	65.5
Regal	742	78	68	82	94	34	31	100	99	77	73	62.8
Rex	1113	75	63	92	98	32	51	100	80	51	74	62.7
Newal	1089	82	57	100	79	29	29	100	98	63	72	63.3
Byng	—	83	56	100	88	16	46	93	93	42	72	61.6
Michigan	—	90	62	100	94	28	20	100	73	41	71	62.1
H. medicum	—	70	55	98	67	8	12	100	95	14	63	55.7
Plush	1117	42	61	96	84	10	10	100	89	24	62	54.3
S.B. × Trebi	—	57	45	99	64	16	14	100	78	2	59	53.3
Smyrna	859	67	38	98	21	12	4	95	98	1	54	49.1
Trebi	753	63	44	98	35	11	9	100	86	2	56	50.9
Titan	1164	58	66	96	26	8	4	96	96	3	56	49.8
Cal. Mariout	1083	77	54	99	28	5	2	87	97	26	56	49.3
Reka	743	62	57	71	32	10	3	98	84	—	52	46.2
Black Barbless	—	58	44	91	33	4	2	99	82	3	52	49.3
Prospect	1140	73	58	98	19	13	5	81	65	2	52	46.0
Type Pusa 21	—	50	33	98	24	7	2	96	98	—	51	46.9
Pros. × Stav. 3825	—	90	42	69	15	6	4	100	81	1	51	46.4
H. zecofence	—	27	48	90	16	4	10	99	79	32	47	43.4
Gatami	717	52	42	49	23	5	2	100	98	1	46	44.1
Pros. × Stav. 3823	—	45	28	86	16	8	4	87	92	1	46	42.0
Type 4, Punjab	—	40	26	78	18	5	4	84	98	—	44	41.2
H. persicum	—	22	41	68	14	4	2	88	98	1	42	39.6
Glacier	1149	30	36	70	8	10	1	63	88	2	38	36.2
H. pallidum	—	20	20	32	1	4	2	36	99	—	27	29.3
Landsdale	1054	18	21	22	1	4	2	20	90	—	22	25.5

* The minimum significant difference between converted means = 11.0 units.

In order to estimate the magnitude of the interaction in relation to varietal differences the mean value for each variety for each test, omitting Nobleford, was converted to $\sin^2\theta$ and the data were analysed by variance. The mean square for varieties was compared with that for variety-test interaction and found to be highly significant, $F = 9.44$, 1 per cent point $= 1.80$ (about). The means of the converted values together with the minimum significant difference, as calculated from variety-test interaction, are also presented in Table 2.

These results show clearly that on the average of the eight tests varietal differences were established. The magnitude of the differences was substantial, varying from 22 per cent for Lansdale to 84 per cent for Canadian Thorpe. Among the varieties of commercial importance in this area, O.A.C. 21, Regal, Rex, and Newal were susceptible; Plush, Trebi, and Titan were moderately susceptible; and Glacier was moderately resistant.

TESTS OF HYBRID LINES

Materials and Methods

A cross was made between the varieties Prospect and Hannchen. Prospect is an early-maturing, six-rowed, smooth-awned variety with an erect spike and is moderately resistant to grasshopper damage. Hannchen is a late-maturing, two-rowed, rough-awned variety with a nodding spike and is susceptible to grasshopper damage. The hybrids produced were grown as bulk plots without selection until the F_5 generation. At that time 100 plants representative of the various types present were selected. These were increased and 98 of them were used in these tests.

The 98 lines were grown at four stations, Gravelbourg, Shaunavon, Herschel and Burdett, in 1947. They were included in the regular varietal test and were grown in the manner and under the same conditions as described for the varietal tests. Notes on damage were also taken and data analysed as described.

Results

Significant differential damage between the hybrid lines was obtained in each of the four tests. Damage to most of the hybrid lines was intermediate between the two parents. While experimental error was probably responsible for the majority of the lines that fall outside the parental limits, the results suggest that some transgressive segregation occurred.

A summary of the distribution of the hybrid lines for grasshopper damage is presented in Table 3. At Gravelbourg and Shaunavon, the distribution was skewed toward the resistant parent. At Herschel and Burdett, most of the hybrids were classified as susceptible. This is probably a direct reflection of the time and intensity of the infestation at the different locations. The greater the degree of infestation the more likely that all the material will be destroyed.

These data are not sufficient to warrant any statements as to the probable number of genes involved in reaction to grasshopper attack. It would be expected that this would be a complex character governed by several genes. No results were obtained that would make this seem improbable.

TABLE 3.—DISTRIBUTION OF HYBRID LINES AND PARENTAL VARIETIES FOR GRASSHOPPER REACTION

Station and material	Number of lines falling into each class									
	Grasshopper damage in per cent									
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Gravelbourg—										
Prospect × Hannchen	10	36	35	9	6	—	1	1	—	—
Prospect	—	1	—	—	—	—	—	—	—	—
Hannchen	—	—	—	—	—	—	—	—	1	—
Shaunavon—										
Prospect × Hannchen	32	21	15	9	8	7	3	2	—	1
Prospect	1	—	—	—	—	—	—	—	—	—
Hannchen	—	—	—	—	—	—	—	—	1	—
Herschel—										
Prospect × Hannchen	—	—	1	—	2	5	11	21	21	37
Prospect	—	—	—	—	—	—	1	—	—	—
Hannchen	—	—	—	—	—	—	—	—	—	1
Burdett—										
Prospect × Hannchen	—	—	—	—	—	1	2	4	15	76
Prospect	—	—	—	—	—	—	—	—	1	—
Hannchen	—	—	—	—	—	—	—	—	—	1

ASSOCIATION BETWEEN MATURITY, PROTEIN CONTENT AND DAMAGE AMONG VARIETIES

In order to study the effect of growth period of the varieties in relation to grasshopper damage, replicated plots of the varieties under test were grown under grasshopper-free conditions at Swift Current in each year and the dates of heading were noted. When grasshoppers are present it is not always possible to accurately evaluate maturity because of damage. Under droughty conditions, which frequently occur at Swift Current, days to head is considered a better index of maturity than days to mature.

The protein content of the straw was determined as follows. Straw samples of each variety were collected from two replicates of the tests grown at Cabri and Swift Current in 1946. Thus, four samples were collected from each variety. They were taken in the same day shortly after all varieties had headed, hence, early-maturing varieties were in a more advanced stage than later-maturing ones. The samples were ground, and the nitrogen content was determined by the Kjeldahl method. The factor 6.25 was used to convert nitrogen to protein. The averages of the four determinations were used for correlation studies.

Grasshopper damage in each test was correlated in turn with days to head at Swift Current and with average protein content of the 1946 samples grown at Cabri and Swift Current. Protein content was also correlated with days to head for each of the years 1944, 1945, and 1947.

The correlation coefficients obtained are presented in Table 4.

Significant positive correlations between grasshopper damage and days to head were obtained in all tests except Herschel. In the latter a non-significant negative correlation was obtained. The magnitude and con-

Table 4.—Coefficient of correlation between grasshopper damage, protein content and days to head

x = Grasshopper damage in per cent. y = Per cent protein in straw, 1946.
z = Days to head at Swift Current.

Station	No.	Year	Correlation coefficients			
			xy	xz	yz	xy.z
Swift Current	33	1944	0.462**	0.590**	0.623**	0.149
Sask. Landing	33	1944	0.372*	0.658**	—	−0.064
Carmangay	33	1944	0.256	0.520**	—	−0.102
Nobleford	35	1945	0.753**	0.792**	0.661**	0.462*
Cabri	40	1945	0.697**	0.830**	0.598**	0.450*
Burdett	42	1947	0.422**	0.566**	0.575**	0.142
Gravelbourg	42	1947	0.746**	0.684**	—	0.592**
Shaunavon	42	1947	0.838**	0.704**	—	0.745**
Herschel	42	1947	0.166	−0.124	—	0.290

* Exceeds 5 per cent point.
** Exceeds 1 per cent point.

sistency of the correlation coefficients suggest a moderately close relationship between these two characters. Early-maturing varieties tend to be resistant and late ones susceptible.

Protein content and grasshopper damage were positively correlated in seven of the nine tests. Again a non-significant value was obtained at Herschel. The relationship between protein content and damage indicates that the grasshoppers tended to feed most extensively on high-protein and to avoid low-protein material.

As would be expected, protein content and days to mature were positively associated in each of the three years. It has been well established that the protein content of the straw diminishes as maturity advances and it will be recalled that these samples were all taken at the same time; hence, varieties differed in stage of maturity.

The partial correlations between damage and protein content when maturity was held constant show that in only four of the nine tests was a significant value obtained. Thus in only about one-half of the tests could the variation in damage be ascribed to differences in protein content.

ASSOCIATION BETWEEN DAMAGE AND SOME AGRONOMIC CHARACTERS AMONG HYBRID LINES

Grasshopper damage to the hybrid lines from the cross Prospect × Hannchen was studied in relation to days to head, awn barbing, rows of grain per head, and the degree of nodding exhibited by the spikes at maturity. Notes on these characters were taken on material grown under grasshopper-free conditions at Swift Current. The lines were classified as rough, smooth, or segregating for awn barbing; and as two-rowed, six-rowed, or segregating for rows per head. In classifying the degree of nodding the average angle of the vertical of the spike at maturity was estimated. Thus, an erect spike would be given a value of zero, one at right angles to the stem a value of ninety, and so on.

FIGURE 1. Grasshopper damage to barley, Cabri, 1945.
Rows from left to right are:

Pros. × Stav. 3823	15 per cent damage.
Pros.	20 per cent damage.
Canadian Thorpe	100 per cent damage.
Rex	100 per cent damage.

FIGURE 2. Grasshopper damage to barley—Burdett, 1947.
Rows from left to right:

Pros. × Hann. 4614	5 per cent damage.
Hannchen	100 per cent damage.
Pros. × Hann. 4653	50 per cent damage.

FIGURE 3. Grasshopper damage to barley—Burdett, 1947.
Rows from left to right are:

Lansdale	5 per cent damage.
Pros. × Hann. 4606	100 per cent damage.
H. pallidum	5 per cent damage.

The grasshopper damage at each of the four tests was related to days to head and degree of nodding by means of correlation coefficients and to awn barbing and rows per head by means of the X^2 test.

The correlation coefficients between damage and days to head at each of the stations were as follows: Gravelbourg 0.451, Shaunavon 0.621, Herschel −0.274, and Burdett 0.394. All were significant at the 1 per cent point. The positive associations at the three stations were similar to those reported from the varietal tests. The small but highly significant negative correlation at Herschel compares with a non-significant negative correlation among the varieties at this station. Despite the results at Herschel, the positive association between damage and maturity seems to be reasonably well established.

The correlation coefficients between damage and degree of nodding at each of the stations were as follows: Gravelbourg 0.141, Shaunavon 0.005, Herschel 0.396, and Burdett 0.196. The value for Herschel is significant at the 1 per cent point, that for Burdett at the 5 per cent point, and the other two values are non-significant. It was thought that nodding types might be more susceptible to damage than erect types, because the former are more prone to break even without grasshopper feeding. In view of the low correlation coefficients obtained, it is believed that the degree of nodding is of little or no importance in explaining varietal differences in damage caused by grasshoppers.

When awn barbing and the number of rows per head were tested in relation to damage using the chi-square test, no associations were established.

DISCUSSION

The results of the present investigation show clearly that barley varieties differ greatly in their reaction to head dropping caused by grasshoppers. The expression of these differences depended upon both the time and the severity of the grasshopper infestation. The most striking differences were found when a moderate infestation occurred. Severe infestations resulted in considerable damage to even the most resistant of the varieties tested. There was no evidence of varietal differences when the crop was attacked in the seedling stage, but there was only one test under these conditions. Moreover, at this test infestation was very severe and present before the crop emerged. On the other hand, grasshoppers attacked the varieties at Cabri, 1945, well before the earliest variety had headed and an excellent differential was obtained.

While differential damage to varieties has been demonstrated, the economic significance of this phenomenon has not. It can be argued that, if a resistant variety were grown over a wide area so that the grasshoppers did not have a choice, it would suffer as much damage as if a susceptible variety were grown. It would be difficult to design an experiment to prove or disprove this statement, but it seems reasonable to assume that the use of a resistant variety would reduce losses. Certainly many producers agreed that the use of Ceres wheat reduced grasshopper losses because of its comparative resistance. Even if only resistant varieties were grown, the grasshoppers would have some choice in most cases. There are native

plants on the roadsides and ranges together with weeds in the fields that they might prefer to a resistant crop. Even if there were no choice, it is the authors' opinion that damage would be lessened. It has been observed on many occasions that, when grasshoppers land on a susceptible variety, they begin feeding at once and continue for a considerable period. When they land on a resistant variety, feeding is tentative. The insect moves up and down the stem and from stem to stem doing very little feeding.

The use of resistant varieties, even if they failed to reduce damage, might have an important effect on grasshopper numbers. The fact that grasshoppers need specific hosts for maximum longevity and fecundity has been demonstrated by several investigators, especially by the researches of Criddle (9), Isley (16), Sanderson (24), Hodge (13), Tauber, Drake and Decker (28), and Brett (6). A common characteristic of these tests was that different crops were tested as food for grasshoppers and not varieties or selections within a species. In view of the striking effect on the longevity and fecundity of grasshoppers when fed different crops, and of the fact that grasshoppers show a marked preference for certain varieties within a species, it would not be unreasonable to expect similar, but perhaps less striking, differences in these characters if the grasshoppers were fed on varieties for which they have a natural aversion. Smith (26) was able to vary the survival and fecundity of *Melanoplus mexicanus mexicanus* (Sauss.) by feeding them on wheat seedlings that varied in nitrogen content. High nitrogen seedlings resulted in high survival and maximum fecundity. Even a small difference in fecundity might have an important effect on numbers over a period of years.

Although the economic value of grasshopper-resistant barleys has not been clearly demonstrated, it is a characteristic that might well be considered by barley breeders in areas where this insect is a pest. The production of resistant hybrids would offer problems in the elimination of susceptible segregates. In the first place, the plants must be grown in an area where grasshoppers are likely to occur. The location of such areas cannot always be predicted with certainty. In the present investigation excellent differentials were secured in seven of the twelve tests. A fair differential was obtained at one other, and at another the results were in disagreement with all other tests. Three failed to produce a differential of any kind. Furthermore, areas suitable for testing are frequently a considerable distance from a plant breeding station; thus, the expense of conducting the program is substantially increased.

These difficulties could be partially overcome by using an associated character as an index of resistance. The relationship between earliness and resistance demonstrated in the present study would be especially useful if earliness was also a desired characteristic in the breeding program. The relation of mechanical tissue to resistance has not been studied in barley but the strong relationship between these characters found in wheat by Hehn and Grafius (11) suggests that a similar relationship might exist in barley.

The use of greenhouse tests or field cages has not been investigated in this study, but they offer possibilities as a means of producing differential environments at will.

Further investigation of the association between grasshopper damage and protein content is probably warranted. Under conditions of moderate infestation in this present study, there was a highly significant positive association between these two factors, even when maturity was held constant. When large numbers of grasshoppers were present the partial correlation coefficients were not significant. Under such conditions this non-association might be expected since competition for food would tend to obscure the preference for high protein material. There remains the possibility, of course, that some quantitative character other than protein is responsible for the preferential feeding of grasshoppers on barley varieties.

The relationship between earliness and resistance is an interesting one. It might suggest that the resistance of early types is due to their being less attractive at the time of damage than late ones. As they neared maturity, the early ones would be lower in moisture content, minerals and protein, and higher in lignin content, than the late ones. If this were the cause of the resistance observed, early varieties when seeded late would be equally as susceptible as late ones. While the lower moisture content or other characteristics of early varieties may have been a factor in accounting for differences in some of the tests, it is not regarded as being an important one. In the first place, the best differential was secured at Cabri in 1945 when damage commenced before the crop headed. It is improbable that maturation was a factor in this test. Secondly, among the hybrid lines a negative correlation was established in one test. Thirdly, on the basis of one year's test at four stations, certain early hybrid lines were relatively susceptible and certain late lines relatively resistant. These lines are being tested further to definitely establish the existence of early susceptible and late resistant types.

It is of interest to note that there does not appear to be any strong relationship between maturity and damage in wheat, according to the data published by Jacobson and Farstad (17) and Hehn and Grafius (11). In some preliminary tests conducted by the junior author, a small but significant negative correlation was established between maturity and damage in wheat varieties.

The hypothesis advanced to explain the situtation is that the expression of both earliness and grasshopper resistance in both barley and wheat is controlled by several genes. In barley some of the genes for earliness are linked with those for resistance, whereas in wheat they are not. Proof of this hypothesis awaits further investigation.

SUMMARY

A series of from 36 to 42 barley varieties were grown in replicated plots during the years 1944-1947. They were grown at various stations and, in all, twelve tests were conducted. These tests were exposed to grasshopper attack and the percentage of heads dropped by the grasshoppers on each plot was recorded. Significant varietal differences in the amount of damage sustained was established in nine of the twelve tests. In two tests grasshoppers were not present in sufficient numbers to cause damage

and in one test the varieties were all destroyed in the seedling stage. Thirty-two varieties were common to eight of the tests. Significant varietal differences based on the average of the eight tests were established.

In eight out of nine tests significant positive correlations were established between grasshopper damage and days to head. The protein content of the straw was positively correlated with damage in seven of the nine tests. When partial correlations were calculated with days to head held constant, protein content was significantly correlated with damage in only four of the nine tests.

Ninety-eight lines from the cross Prospect (moderately resistant) × Hannchen (susceptible) were tested at four stations in 1947. The reading on most lines fell between those of the parents, but there were a few that fell outside these limits. At two of the tests the distribution of the lines was skewed toward the resistant parent, whereas in the other two it was skewed toward the susceptible parent.

Damage to the hybrid lines was positively associated with days to head in three and negatively associated in one of the four tests. There was no association between damage and awn barbing or damage and rows per head. There was some association in two and no association in the other two tests between damage and degree of nodding of the spike.

Varietal differences in grasshopper damage are considered to be of economic importance and as such should receive consideration in barley breeding programs. The hazards of producing a differential environment and the use of associated characters as a means of discarding susceptible segregates are discussed. It is considered that the association between damage and time of maturity is most likely due to genetic linkage rather than to the escape of early types.

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A NEW VARIETY OF OATS FOR EASTERN ONTARIO[1]

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A new oat variety called Lanark C.A.N. 733 is being made available to growers in eastern Ontario for the 1951 crop.

This variety has limited adaptation and is being recommended only in those areas of eastern Ontario where rust is prevalent and where early maturity and good straw are of special importance.

Lanark originated from the cross Onward × (Anthony × Bond) made in the Agronomy Division, Plant Research Bureau, Department of Science and Industrial Research at Lincoln, New Zealand. Crossed seeds were sent to Ottawa for propagation during the summer of 1938 and the crop returned in the fall in time for normal seeding in New Zealand. By request, a few seeds from the above cross were retained at Ottawa and from these seeds Lanark was developed.

CHARACTERISTICS

Lanark is early maturing with straw of average size, height and good lodging resistance. The grain is classed as medium large and moderately low in hull percentage. It is not heavy tillering, which character along with its earliness and lodging resistance makes it well adapted for use in a mixture with barley or for a nurse crop. The outer glumes, and in some years the flowering glumes, have a brownish discoloration which resembles a glume blotch. This discoloration, however, is not associated with a disease organism but is a varietal characteristic.

Lanark is resistant to both loose and covered smuts and has resistance to races 1, 2, 5, 8 and 10 of stem rust and to all common races of crown rust except 33, 34 and 45. It is resistant also to Victoria blight.

[1] Contribution No. 160 from the Cereal Division, Experimental Farms Service, Canada Department of Agriculture, Ottawa, Canada.

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